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ANALYSING FILM PLASTIC WASTE IN RESIDENTIAL CONSTRUCTION PROJECT

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ABSTRACT

Sustainability and lean construction are closely interrelated topics to consider. However, sustainability issues in construction projects are rarely discussed in International Group for Lean Construction (IGLC) community. The major aim of this research is to analyze the film plastic waste in residential construction project. For the analysis, three cases were selected, where the amount and quality of film plastic waste were investigated from the beginning of project to the end. According to the results, 1009–1710 kg of film plastic waste was separately collected (about 0.5–1.0% of total waste). In addition, the generated pattern of film plastics was approx. 0.34 kg/m2 and each apartment generated approx. 26.20 kg. The most film plastic is generated in the interior phase of the work stage, which includes tasks such as partition work, furniture installation and home appliance installation. Furthermore, based on the results of this research, we have developed a preliminary web modelling tool: kalvomuovi.fi, which could be adopted for estimating the amount of film plastic waste in a residential construction project. Future research could further develop the web model tool for other type of construction projects, such as, schools, hospitals, and shopping centers. Also, future research is necessary to develop better recycling technology of film plastic waste.

KEYWORDS

Green construction, film plastic waste, modeling platform- kalvomuovi.fi, lean construction

INTRODUCTION

Green construction and plastic use are currently an issue of major concern that has sought significant attention of media, policymakers, environmental activists, as well as academic practitioners (Mikkonen et al., 2020; Häkkinen et al., 2019; Ramboll, 2020; Yle, 2021). The main concern with the dramatic increase in the use of plastic has been its significant and adverse effect on human health, as well its potential contribution to climate change and environmental degradation and toxicity.

According to Material Economic (2018), the plastic use is increasing by 10 million metric tonnes per year, and it is estimated to reach 800 million metric tonnes per year by 2050. The plastic industry is intricately linked to the global economy. It is considered the seventh most value-adding industry in Europe, which consists of about 60000 companies and provides about 1.5 million jobs with a value of about 350 billion euros (Häkkinen et al., 2019). Muoviteollisuus (2021) estimates that in Finland the plastic industry consists of almost 600 companies and employs over 10,000 people. It is estimated that, on average, Finnish residents produce about 15 kilos of plastic waste per year (Yle, 2020). In response to this problem, Kosonen and Varis (2019) presented a plastic roadmap for Finland, which suggests several actions for reducing, reusing, recycling, and replacing plastic.

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Due to various advantageous properties of plastic, such as lightweight, flexibility and dielectric properties, it has been used in different applications. Häkkinen et al., (2019) mentioned that about 45 % of plastic is used for packaging, 19% is used for construction, 12 % in consumer products, 7% in transportation, 4 % electronics and 12 % is used for other applications. They further indicated that a very small portion (about 10%) of plastic is recycled while the rest is discarded which ultimately end up in landfill.

The use of plastic in building and construction improves the physical health of a building by ensuring good thermal moisture and gas insulation performance (Schiavoni et al., 2016). In construction, plastic is used in building products and materials, for instance, flooring, windows, insulation products, and kitchen. Plastic is present in construction products, as a building material, and film plastic is also used for packaging construction materials.

In fact, it has been argued that film plastic is used significantly in construction activities, for instance, for construction product packaging, site workers' food packaging, and also during different work stages (Ramboll, 2020). A few studies have analysed the plastic packaging waste in construction (E.g. Pericot et al, 2014; Pericot and Merino, 2011; Selke and Culter, 2016). They mention that primarily plastic packaging waste were the films. However, their results include the sheets and rigid forms of packaging plastics (e.g. crates). Also, the research on packaging plastic waste excludes the films produced on site, for instance, films used in site protection and site works and activities. Film plastic normally ends up in the landfill due to difficulties in the recycling centres. For all those reasons, research on film plastic waste is explicitly necessary. To the best of our knowledge, till date there has been no research on the use of film plastic in construction. Specifically, this research aims at answering the following research questions:

- How to collect film plastic waste from a construction site?
- How much film plastic waste is created in construction projects (mostly residential)?

THEORETICAL BACKGROUND

PLASTIC IN CONSTRUCTION

According to Plastic Europe (2020) about 4000 million metric tonnes of plastic was produced from 1950 to 2019. This amount mainly includes, polypropylene (PP), polyvinylchloride (PVC), polyethylene (PE) polyethylene terephthalate (PET), polyurethane (PU), polystyrene (PS), and polyester (PES) (Häkkinen et al., 2019; Napier, 2016). Table 1 presents the plastic type composition, physical properties, and possible application in construction.

Table 1: Plastic types and possible application in construction (Awoyera and Adesina, 2020

Plastic types	Physical properties	Application in construction
HDPE	Rigid	Table, chairs, plastic lumber
LDPE	Flexible	Bricks and blocks
PP	Hard and flexible	Aggregates in asphalt mixture
PS	Hard and brittle	Insulation material
PET	Hard and flexible	Fibres in cementitious composites
PC	Hard and rigid	Aggregates in cementitious composites

Even though various types of plastics are used in the construction sector; PVC, Polyethylene-high density (PE-HD), Polyethene low density (PE-LD), PP and EPS (Expanded Polysterene) are mostly common. Table 2 presents the types of plastic generated in the building and construction sector in the EU in 2018 (Plastic Europe, 2019).

Table 2: Building and construction plastic waste generation in the EU in 2018 (in kt)

Plastic types	Total waste generation	Recovery	Disposal/landfill
PE-LD	90	70	20
PE-HD	225	164	61
PP	130	95	35
PS	30	21	9
EPS	140	95	45
PVC	910	683	228
Other	235	172	63
Total	1760	1300	461

Plastic quantity used in construction depends on building types, products, and work stages. For instance, Monahan and Powell (2011) estimated the use of plastic to be 7.4 kg/m2 in a model-house study. Ruuska and Häkkinen (2015) presented 12-21 kg/m2 in a block of flats. Furthermore, Jeffrey (2011) argued that approximately 1% of total construction demolition to be of plastic. Similarly, Häkkinen et al., (2019) evaluated the quantity and types of plastic in concrete and wooden residential buildings and day care centres. Their findings showed plastic quantity to range from 6 to 28 kg per gross m2.

FILM PLASTIC IN CONSTRUCTION

The demand for film plastic is increasing worldwide. For instance, in 2015, the film plastic demand rose in Asia by 40% and in Western Europe and North America the demand was equally significant (18%) (Stastista, 2015). The increasing demand for film plastic is associated with its diverse applications. Essentially, such applications can be divided into two groups: packaging and non-packaging. In packaging, film plastic is used to protect the product itself, which is called primary packaging, and also film plastic is for safe transportation of the product as a secondary packaging (Hellström and Sagir, 2007; Horodytska et al., 2018). Non-packaging use includes, for example, films from construction, agriculture, trash bags, etc. In general, all plastic could be formed into film plastic, however, based on the polymer application, films from the PE-HD, PE-LD ja PE-LLD (polyethylene linear low-density) is mainly used in construction (Headley Pratt Consulting, 1996; Polymerdatabase, 2021).

Some studies have analyzed the packaging waste in construction. They generally include cardboard, woods, and plastic (Pericot et al., 2014; Pericot and Merino, 2011; Selke and Culter, 2016). Perico and Merino (2011) presented the the packaging waste generated in three construction site cases: 1) 100 social housing projects, 2) 118 dwellings and 3) 112 housing construction projects (table 3).

Table 3: Packaging waste in construction projects in Spain

	Cardboard		Muovi		Wood	
Cases	Weight (kg)	Volume (m3)	Weight (kg)	Volume (m3)	Weight (kg)	Volume (m3)

I (100 blocks)	2887,36	67,31	1691,71	34,73	74832,85	958,58
II(118 blocks)	4039,33	88,25	2320,35	46,25	104457,24	1225,47
III (112 blocks)	4823,45	71,15	2236,54	42,59	99823,66	1167,94
Total= 330 (blocks)	11750,1	226,71	6248,6	123,57	279113,75	3351,99

In our research, the primary focus is on analyzing the presence of film plastic in construction projects. So, while analysing previous literature on packaging waste, our emphasis is on packaging plastic.

Based on the calculation presented by Pericot and Merino (2011) the average plastic packaging waste per middle sized building (~8 floor) is about 19 kg (table 3). They further mentioned that majority of plastic packaging waste was film and sheet plastic, which were used to wrap the pallets. And, one-way slab products were the highest producer of packaging waste in construction projects.

Pericot and Merino (2011) further suggest waste management strategies for reducing plastic packaging waste in construction. They include, for example, segregation at origin by waste specific container at site, wrapping the product until it is going to be used and immediately store packaging waste once the product has been opened. According to them, this would help to maintain the product in better conditions as well as prevent it from potential packaging damages. In addition, the compactors could be used to reduce the plastic volume, and waste management training could be provided to construction staff.

Pericot et al., (2014) further studied the packaging waste of midsized ten housing blocks constructed with the Mediterranean conventional procedure. This includes, for example, deep foundations with concrete piles, one-way slabs, flat roofs, brick facades insulated with polyurethane foam and so on. Table 4 presents the average packaging waste quantities presented in their study.

Table 4: Packaging waste in different construction stages

	Cardboard		Plastic		Wood	
Construction stages	**Weight (kg/m2)**	**Volume (l/m2)**	**Weight (kg/m2)**	**Volume (l/m2)**	**Weight (kg/m2)**	**Volume (l/m2)**
Site remediation	0	0	0	0	0,01	0,01
Foundations	0,01	0,01	0	0	0	0
Structures	0,01	0,02	0,12	0,19	0,33	0,3
Envelopes	0,02	0,03	0,06	0,1	0,6	2,21
Partitions	0,01	0,02	0,12	0,19	0,64	0,59
Building services	0,88	1,18	0,01	0,02	0,13	0,12
Thermal and moisture protection			0,07	0,12		
Roofs	0,02	0,03	0,04	0,07	0,05	0,05
Finishes	0,25	0,34	0,1	0,17	0,15	0,13
Signaling equipment	0,05	0,07				
Exteriors and swimming pool	0,01	0,01	0	0	0,02	0,02
Total	1,26	1,71	0,52	0,86	1,93	3,43

According to Pericot et al., (2014) study plastic packaging waste mainly produced in the partitions (~28%), structures (~20%) and finishes works (~20%). In line with the previous research (e.g. Pericot and Merino,2011; Jang et al., 2020) they also mention that the high portion of plastic packaging waste generated from the palletizing and primarily they include film and plastic sheet.

Even though the research works mentioned above have evaluated the packaging waste in construction, their primary focus was not on the film plastic waste in construction. They mention that the majority of packaging waste was films and plastic sheets. Hanny (2002) explains that a significant portion of the packaging plastic waste included the rigid forms, especially in secondary packaging, e.g. crates and shipping pallets. Selke and Culture (2016) distinguished different packaging plastics as: Plastics with thickness of 0.003 in or less are considered film, and materials with thickness of 0.010 in or greater are considered sheet. Furthermore, studies on packaging plastic that evaluate films produced in the site such as film used for site protection, poly bags and site workers' food packaging, are missing.

FILM PLASTIC COLLECTION METHOD

Different countries have different strategies for waste collection. For instance, in the United States, two types of collection methods are used: 1. single- stream: all the waste (e.g. paper, glass, plastics and metal) are collected in the same bin, and 2. dual-stream: the waste is collected separately, such as, plastic, paper, glass and metal (Cimpan et al., 2015). Even though the dual stream process collects plastic separately, film plastic is rarely separated (Horodytska et al., 2018).

In the EU, some of the member states have adopted film plastic waste collection strategies. However, even in such countries, film plastic is still collected in the mixed plastic bin. Table 5 presents EU countries that have adopted the film plastic collection strategies.

Table 5: Film plastic collection schemes in European countries (Cimpan et al., 2015; Seyring et al., 2015; Horodytska et al., 2018)

Film collection schemes	EU countries
Co-mingled flexible and rigid plastic collection	Austria, Netherlands
Collected with mixed plastics	Germany, Slovenia, Hungary, Sweden, Spain, Portugal
Some collection with mixed plastics	France
Rigid and film plastics are collected separately	Italy
Plastic (PE) films collected separately	United Kingdom
Collected with mixed recyclables	Ireland

To evaluate the packaging plastic waste from construction site, Pericot and Merino (2011) used a tool called "SMARTAudit" where waste was quantified and categorized by source, type, number, cause, and cost. In this process, well-trained observers evaluated the volume of waste from the mixed waste container at construction site. However, they recommend placing separate plastic waste containers on construction sites for proper waste management.

Overall, the collection of film plastic waste from a construction site is not an easy task. The site needs to be equipped with different collection bins, which is not always viable. Collection may face several challenges such as busy environment of the site, lack of space, attitude of people towards waste sorting, etc. (Ministry of Environment, 2020). Even though the collection of film plastic seems to be time-consuming and extra work, it has been argued that construction projects would still benefit from avoided waste collection fees (Ramboll, 2020).

METHOD

Case study is appropriate research for in-depth investigation and multi-faceted understanding of a complex topic (Yin, 2018). Multiple sources of evidence are used in this research approach. Thus, this research is conducted based on the multiple case study approach.

For analysis, three building construction projects were selected for the in-depth investigation. They are presented in table 6. All the cases have implemented some techniques of lean. For example, all projects have adopted prefabricated products. They have adopted waste (material and process) minimization techniques, e.g., Choosing-by-advantages (CBA) in design and construction phase. The cases were selected to ensure that the amount of film plastic could be collected from the beginning of the project to the end.

Table 6: Case information and amount of film plastics

	Case 1	Case 2	Case 3
Gross area (m2)	3863 m2	5617 m2	3460 m2
Number of apartments	54	76	38
Number of floors	7	9	8
Collected film plastic waste	1596 kg (0,96 % of all waste)	1710 kg (0,53 % of all waste)	1005 kg
Film plastic waste / m2	0,41 kg /m2	0,30 kg /m2	0,29 kg /m2
Film plastic waste/ apartment	29,6 kg	22,5 kg	26,4 kg

For collecting the data, we agreed with our case projects that they would collect film plastic separately. For this, all site workers were instructed to collect the film plastic separately. To ensure that the film plastic measurement was accurate, a separate film plastic container with instructions was placed on every floor. Film plastic waste was collected in the dedicated container and measured.

According to Poon et al (2001) building construction workers are often reluctant to conduct on-site waste sorting which is considered to be time consuming and labor intensive. To address this issue, our case projects also instructed their cleaners to place film plastic waste into the right container. In addition, the project researchers also visited the site often to analyze the amount of film plastic in other containers and at the same time observed the quality of film plastic in different work stages. The amount of film plastic was obtained from the waste collector. The amount was further corrected with the amount thrown into the wrong container, even though it was almost negligible.

RESULTS AND ANALYSIS

RESULTS FROM TASK LEVEL ANALYSIS

Firstly, the amount of the films waste produced in each activity listed on the schedule was analyzed separately for our cases. The activities that required several products to be installed naturally generated bigger portion of the film's plastic. Table 7 presents the major task-level activities that generates the greatest amount of film plastic.

Table 7: task-level activities that generates the highest amount of film plastic

SN	Task -level activities	Case 1 (kg)	Case 2 (kg)	Case 3 (kg)
1	Furniture installation	187,42	112,64	65,14
2	Ceilings of apartments	121,51	93,87	43,43
3	Partition work	93,31	93,87	52,73
4	Wooden windows and balcony doors	92,22	156,45	67,21
5	Laminate	88,91	93,87	20,68
6	Wall tiling	84,57	112,64	68,24
7	Roof	75,01	35,20	38,77

8	Leveling works	67,52	112,64	43,43
9	Final cleaning	65,25	156,45	51,70
10	Bathroom installations	59,27	56,32	55,83
11	Aco wall installation	55,74	117,34	15,51
12	other	605,00	568,20	485,75
	Total	**1596,00**	**1710,00**	**1009,19**

After analyzing the amount of film plastic waste in each activities of our cases, we then organized tasks in the following five construction stages, which allow the comparison of the results obtained in every project:

1. Foundation: Foundation wall, Foundation pillars, beams
2. Frame and roof: Frame of building, roof work
3. Interior work: Partitions, furniture installation, home appliance installation
4. MEP installation: Mechanical, electrical and plumbing work
5. Finishes and closures: Operational tests, official inspections

TOTAL AMOUNT OF FILM PLASTIC WASTE

In all cases, the portion of the film plastic waste was about 0.5-1% of total waste. The total amount of film plastic ranged from 1005 kg to 1710 kg. According to the U.S. Environmental Protection Agency (2016)'s volume-to-weight conversion, 1 kg of film plastic will occupy 0.05 m^3 of container space if the films are stored without heavy compression. This conversion is used to evaluate the volume of film plastic in our cases. Table 8 presents the number of films produced in each site per works stages and their volume:

Table 8: Total amount of film plastic in each case

SN	Tasks	Case 1 (kg)	Case 1 (m3)	Case 2 (kg)	Case 2 (m3)	Case 3 (kg)	Case 3 (m3)
1	Foundations	45,39	2,27	31,29	1,56	27,92	1,40
2	Frame and roof	156,11	7,81	132,98	6,65	183,01	9,15
3	Interior work	819,20	40,96	934,01	46,70	548,51	27,43
4	MEP installation	573,05	28,65	596,08	29,80	244,39	12,22
5	Finishes and closures	2,26	0,11	15,65	0,78	5,17	0,26
	Total	**1596,00**	**79,80**	**1710,00**	**85,50**	**1009,00**	**50,45**

As table 8 demonstrates, film plastic was mostly produced in the interior Workstage. It's mainly due to the activities such as partition work, furniture installation and home appliances installation—where most of the product required installation and their packaging plastic constituted the high amount. On the other hand, a minimal amount of film plastic waste was generated in finishes and closures. This is apparently because this stage involved mostly administrative tasks where no product installation is required.

Following the trend that interior activities produce most of the film waste, we have considered that the total area of the building and the number of apartments is the major factors for film plastic waste production. It is also visible in table 12 that case 1 produces the greatest amount of film waste, mainly due to the higher gross area and number of apartments. The total amount of film plastic generated in respect to gross area is presented in table 9.

Table 9: Total amount of film plastic per 100m2

NRO	Tasks	Case 1 (Kg/100m2)	Case 2 (kg/100m2)	Case 3 (kg/100m2)	Average (KG/100m2)
1	Foundations	1,17	0,56	0,81	0,85
2	Frame and roof	4,04	2,37	5,29	3,90
3	Interior work	21,21	16,63	15,85	17,90
4	MEP installation	14,83	10,61	7,06	10,84
5	Finishes and closures	0,06	0,28	0,15	0,16
	Total	**41,32**	**30,44**	**29,16**	**33,64**

While comparing the three case results, case 1 has produced the higher amount of film plastic waste. However, case 2 has the higher gross area and number of apartments. Citing the discussion with case 2 project personnel, some amount of film plastic was thrown into the other containers by mistake by the site workers. And, from our site visit observation and discussion with the project personnel, film plastic was collected as accurately as possible in case 1. Table 10 further presents the films plastic waste per apartment. Analyzing the result of the three cases, each apartment of residential building will produce about 26.20 kg of film plastic waste.

Table 10: Amount of film plastic waste per apartment

SN	Tasks	case 1 (Kg)	Case 2 (KG)	Case 3 (kg)	Average (KG)
1	Foundations	0,84	0,41	0,73	0,66
2	Frame and roof	2,89	1,75	4,82	3,15
3	Interior work	15,17	12,29	14,43	13,96
4	MEP installation	10,61	7,84	6,43	8,30
5	Finishes and closures	0,04	0,21	0,14	0,13
	Total	**29,56**	**22,50**	**26,55**	**26,20**

DISCUSSION

In this research we have analyzed the amount of film plastic waste generated in construction sites. To the best of our knowledge, this is the first research conducted that evaluates film plastic waste from construction site. Some previous studies have analysed the plastic waste, such as, Pericot et al., 2014; Pericot ja Merino., 2011; Häkkinen et al., 2014. However, their study included all type of plastic waste produced in construction sites (e.g., plastic pallets). Our research was solely focused on film plastic waste.

In our case projects, film plastic waste was collected separately onsite. According to Poon et al. (2001), building construction workers are hesitant to carry out on-site waste sorting that is considered to be time and labor demanding. A similar experience was shared in Percot et al.'s (2014) study indicating onsite segregation was around 1.80%. However, in our cases, the sorting rate was about 75% -- this is also mentioned in the project report (Lyytikäinen et al., 2020). It is mainly because in our case projects, film plastic containers were placed in multiple places, e.g., in every floor, yard and a larger film plastic waste container alongside other waste containers. Posters with instructions on waste sorting were stuck on the containers. Furthermore, cleaners were also instructed to correct the waste into the right container if necessary. For those reasons, segregation rate was higher in our cases.

Quantification of plastic waste for each activity is challenging. Pericot et al., (2014) emphasized that the suitable method would be to isolate the different waste categories generated in every activity. However, in practice, it is difficult to follow this procedure without disturbing the construction activities in multi-story residential buildings (Katz and Baum, 2011). To resolve this problem, we have adopted a task-intensity based approach. In this approach, we first analyzed the site activities and scaled them according to the amount of film plastic waste they could generate, in this research we refer that metric as intensity of the task. The intensity marking is discussed and validated with site personnel as well as in project meetings. Thereafter, all our case schedule's task were marked with intensity and evaluated accordingly.

After analyzing film waste amount for each activity, we created a database for film plastic waste produced in each activity of construction site. Based on the database, we developed a model, and it could be used to evaluate the amount of film plastic in future project for residential construction. This could ultimately help for better site waste management plan. Especially, it will help to figure out the size of the container to be placed as well as it will make easier for waste handling company for the frequency needed to pick up film waste which ultimately contribute to cut greenhouse gas emission somehow by avoiding unnecessary truck movement to the site.

Recently, plastic waste as threat to the environment is heavily discussed in academia, industrial professionals and the media. Many scholars discuss that the construction is one of biggest generators of plastic waste. However, there is no statistics available how much approximately amount of film plastic could be produced onsite and it would be necessarily making the waste management plan for the construction site. In this case, our database and model developed based on it, could contribute to develop the standard database, for instance, it could be used by statics Finland, Environmental Protection Agency, etc.

Overall, the findings from this study, specially kalvomuovi.fi platform, is an important initial step for removing plastic waste form construction site. As our platform would help to analyse the film plastic waste at the planning phase, which would help improve the site waste management plan. This would ultimately help to for implementation of Lean and green approach to the construction site.

CONCLUSION

To evaluate the amount of film plastic in construction site, we have evaluated three residential construction projects. To facilitate the most accurate possible measurement of film plastic waste, we have adopted the output method- so that we can measure the waste entering into the site as well as generated within the site. Based on our analysis, film plastic were collected from 1005-1710 kg (about 0,5-1,0 % of all waste) in our cases. The higher amount of plastic films were generated during interior Workstage. This includes the site activities requiring installation of more products e.g., furniture installation, partitions (More detail task level analysis, refer table 11).

Furthermore, while summarizing the analysis of our three cases projects, it showed that 33,64 kg film plastic waste was produced in every 100 m^2 and 26,20 kg was produced per apartment. Based on these results, we have developed a modelling tool that is able to evaluate the amount of film plastic in every work stage for the future projects.

During the site visit, the quality of the film plastic was also evaluated. Quality analyses were mainly based on: a) cleanliness and b) color / brightness. In our analysed cases, portion of the dirty film plastic was very low almost negligible, some cases have collected dirty film plastic in a same container as it used to collected film plastic whereas some have collected in discarded collect in the same container. In any case, the recycling company will clean the films before they process them. Similarly, it is also observed that the portion of non-color film was almost negligible. Thus, the authors did not apply strict rules about color while collecting film plastic.

At the end, based on case study results, the authors developed a platform called kalvomuovi.fi: that can be used to estimate the amount of film plastic waste in residential construction projects.

In this research, the authors analyzed only three cases and based on that, developed a model. For generalization, results from three cases may not be sufficient as the data sample could be considered thin. The model thus requires further testing to validate it for different cases. Also, all of the cases analyzed in this research were residential buildings, so the model presented will only be applicable for residential buildings. Further research is necessary to measure waste from other types of buildings (e.g., hospitals and schools.).

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